

θ_{13} and beyond:

Double Chooz's contributions
to future neutrino measurements

Rachel Carr, Columbia University
on behalf of the DC collaboration

WINP | BNL | February 5, 2015

Double Chooz collaboration



Brazil
CBPF
UNICAMP
UFABC



France
APC
CEA
CNRS/IN2P3:
Subatech
IPHC



Germany
EKU Tübingen
MPIK
RWTH Aachen
TU München



Japan
Tohoku U.
Tokyo I. T.
Tokyo Metro. U.
Niigata U.
Kobe U.
Tohoku Gakuin U.
Hiroshima I. T.



Russia
INR RAS
IPC RAS
NRC Kurchatov



Spain
CIEMAT-Madrid



United States
U. Alabama
ANL
U. Chicago
Columbia U.
UC Davis
UCLA
Drexel U.
IIT
Kansas State
MIT
U. Notre Dame
U. Tennessee
Virginia Tech

Spokesperson: H. de Kerret (IN2P3) **Project manager:** Ch. Veysière (CEA-Saclay)
Website: www.doublechooz.org

Outline

θ_{13} \rightarrow δ_{CP} , mass hierarchy, θ_{23} octant

- ▶ DC's latest and projected measurements
- ▶ DC's unique assets

...and beyond θ_{13} \rightarrow mass hierarchy, sterile ν , ...

- ▶ Techniques and inputs for future experiments
- ▶ Additional physics measurements

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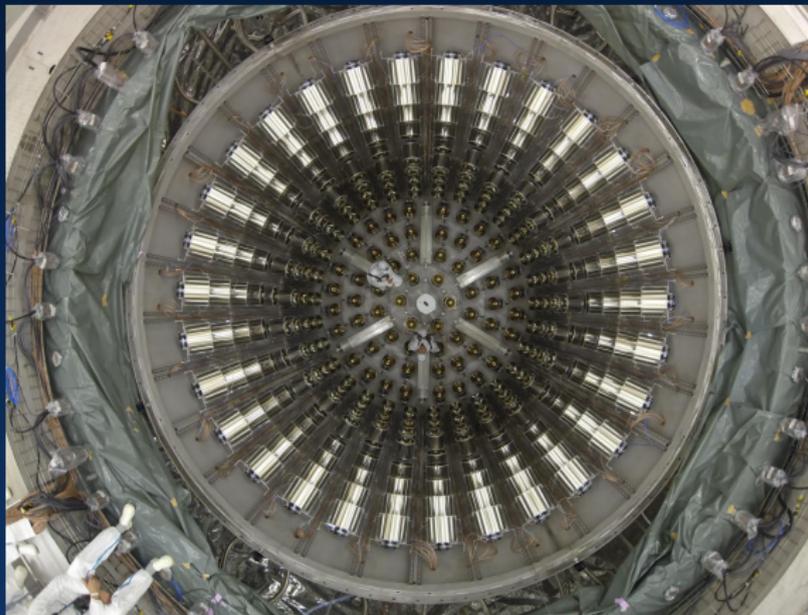
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The Double Chooz experiment



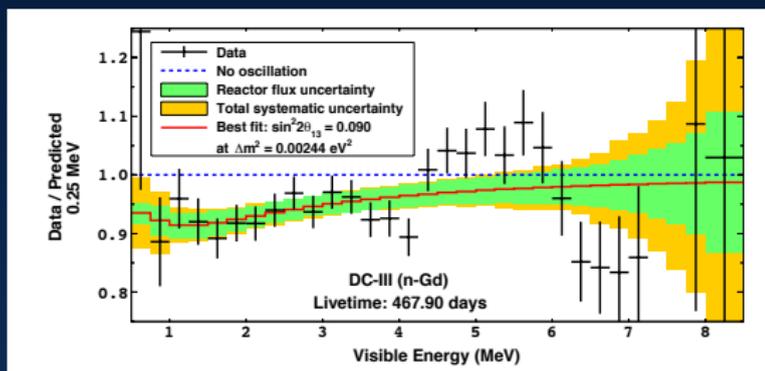
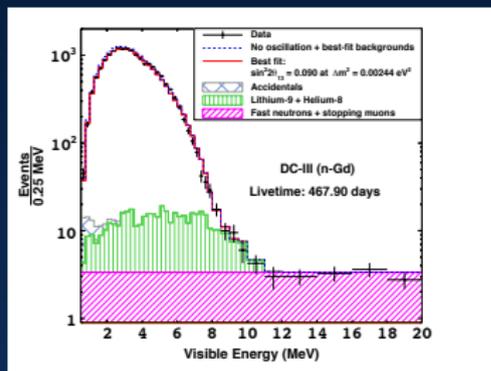
Detector	Baseline to Reactor 1 / 2	Overburden	Start of data-taking
Far	1115 m / 998 m	300 mwe	April 2011
Near	465 m / 351 m	120 mwe	December 2014

Near Detector



Near Detector completed and taking data!
First two-detector analysis expected in 2015.

Latest θ_{13} measurement (Far Detector only)



n-Gd capture analysis of 467.90 live days in Far Detector:

$$\sin^2 2\theta_{13} = 0.090^{+0.032}_{-0.029}$$

JHEP 10 (2014) 086 / arXiv:1406.7763 [hep-ex]

New n-H analysis coming soon.

Estimating future θ_{13} precision

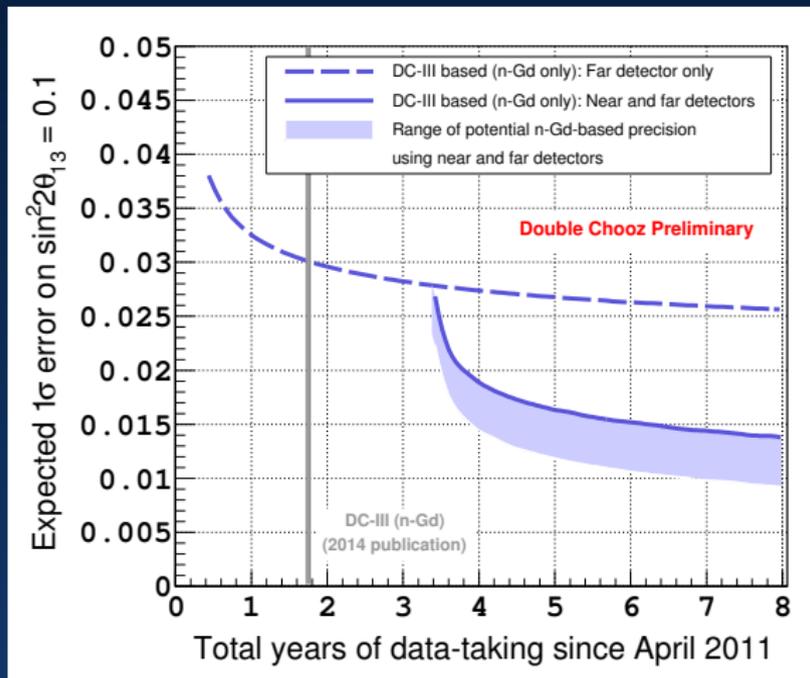
For preliminary projection
based on latest n-Gd analysis (2014):

Event type	Rate (per live day) in		Correlation
	Far Detector	Near Detector	
$\bar{\nu}_e$ signal	37.5 ± 0.7	257.3 ± 3.5	Listed below
${}^9\text{Li} + {}^8\text{He}$	0.97 ± 0.29	4.37 ± 1.31	100% shape, 0% rate
Fast n + stopped μ	0.60 ± 0.05	3.18 ± 0.27	–
Accidentals	0.007 ± 0.005	0.21 ± 0.02	–

Signal uncertainty	Uncorrelated uncertainty in		Correlated uncertainty
	Far Detector	Near Detector	
Detection efficiency	0.20%	0.20%	0.58%
Linear energy scale	0.77%	0.77%	–
Reactor flux	< 0.01%	< 0.01%	1.73%

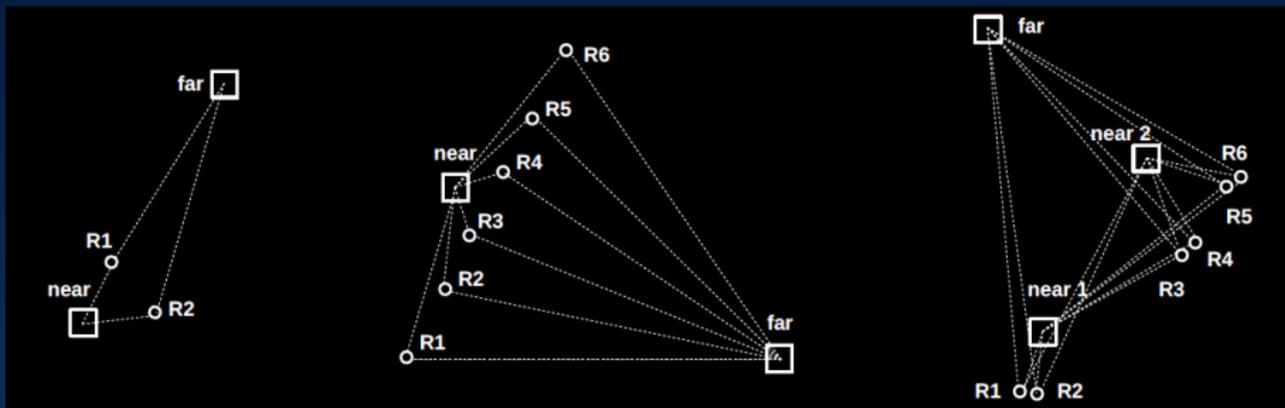
Projected θ_{13} precision

Preliminary projection, based on latest n-Gd analysis (2014):



JHEP 10 (2014) 086 / arXiv:1406.7763 [hep-ex]

Unique Double Chooz assets



Double Chooz

- ▶ Only two reactors
- ▶ Detectors at nearly isoflux points

RENO

Daya Bay

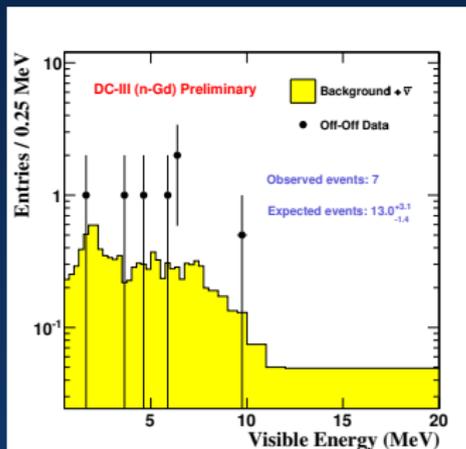
arXiv:1501.00356 [hep-ex]

Reactor-off data



~7 days reactor-off data unique to DC

- ▶ Supports background model
- ▶ Constrains BG in main θ_{13} fit
- ▶ Enables BG-model independent fit



JHEP 10 (2014) 086 / arXiv:1406.7763 [hep-ex],
arXiv:1210.3748 [hep-ex]

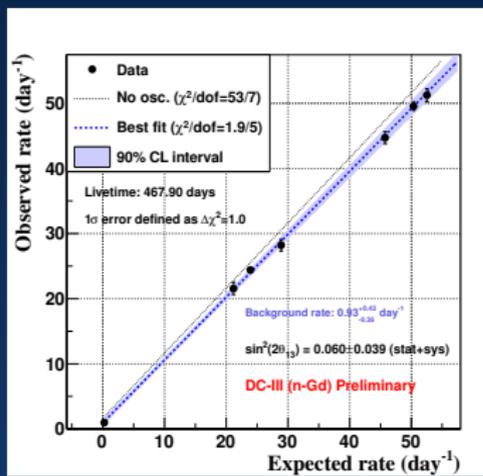
Reactor Rate Modulation analysis



BG model-independent fit: unique to DC

$$\sin^2 2\theta_{13} = 0.060 \pm 0.039$$

n-Gd, 467.90 live days in Far Detector:



JHEP 10 (2014) 086 / arXiv:1406.7763 [hep-ex]

Reactor error suppression from site geometry

Ideal isoflux case

Detectors at isoflux positions (i.e., see identical reactor flux) \Rightarrow Near Detector is perfect flux monitor \Rightarrow Reactor errors 100% suppressed

Estimates for actual experiments:

Experiment	Reactor error suppression from geometry
Double Chooz	92%
Daya Bay	80%
RENO	76%

\Rightarrow DC's final θ_{13} analysis will be BG- (not flux-) limited.

unique to DC

arXiv:1501.00356 [hep-ex] (Independent paper by subset of DC collaborators)

Novel analysis techniques

Currently using/developing: unique to DC

- ▶ Artificial Neural Network-based signal selection
- ▶ Pulse shape analysis for background rejection
- ▶ Nonlinear energy scale in oscillation fit
- ▶ ...

→ Useful both for DC and for other reactor θ_{13} experiments

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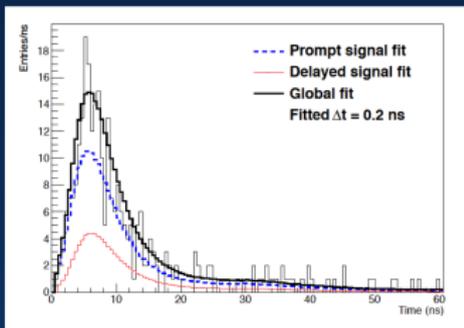
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- ▶ DC's unique assets

...and beyond θ_{13} \rightarrow mass hierarchy, sterile ν , ...

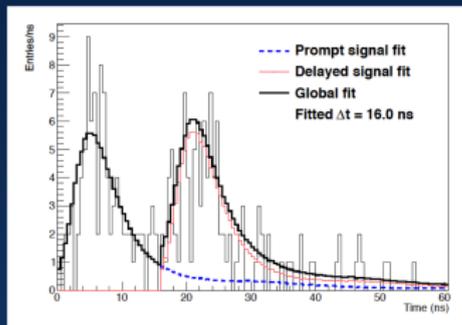
- ▶ Techniques and inputs for future experiments
- ▶ Additional physics measurements

New e^+ (vs. e^-) identifier

- ▶ $\sim 50\%$ of e^+ in DC detector form ortho-Positronium
- ▶ Effective $\tau_{o-Ps} \approx 4$ ns \rightarrow may see delayed γ s in PMT pulse time profile
- ▶ Potential e^+ identifier (signal or BG) in future liquid scintillator detectors



o -Ps formation NOT visible \rightarrow may be e^+ or e^-

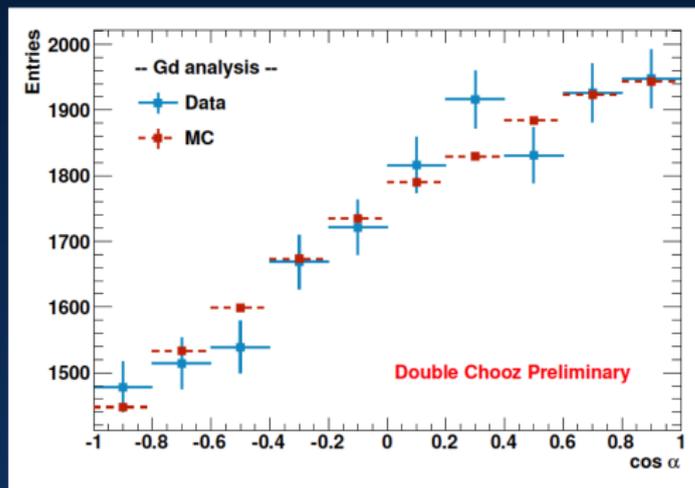
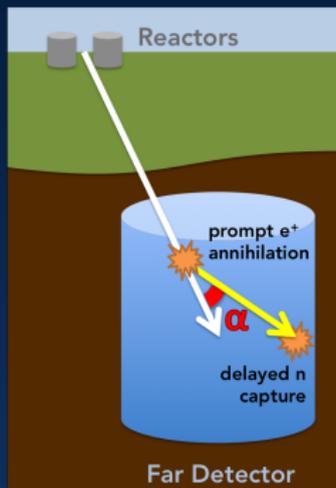


o -Ps formation visible \rightarrow likely e^+

First event-by-event o -Ps identification made in DC.

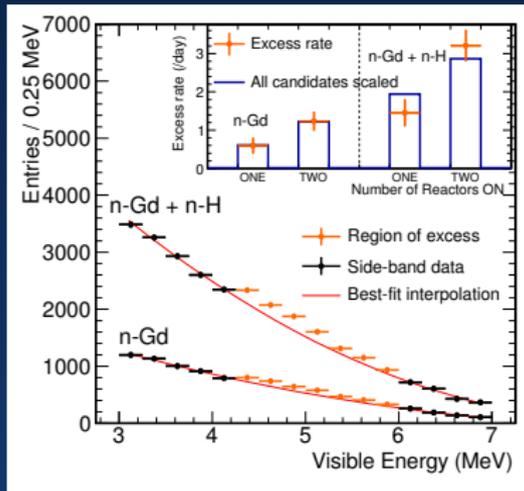
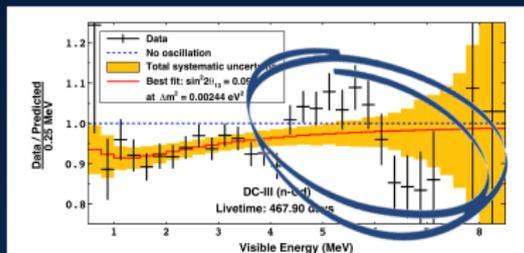
JHEP 1410 (2014) 032 / arXiv:1407.6913 [physics.ins-det]

Neutrino directionality



- ▶ Demonstrated ability to localize neutrino source with n-Gd and n-H data
- ▶ Possible signal enhancer in reactor experiments, even if undoped
- ▶ Also applicable to geoneutrinos, supernova neutrinos, reactor monitoring

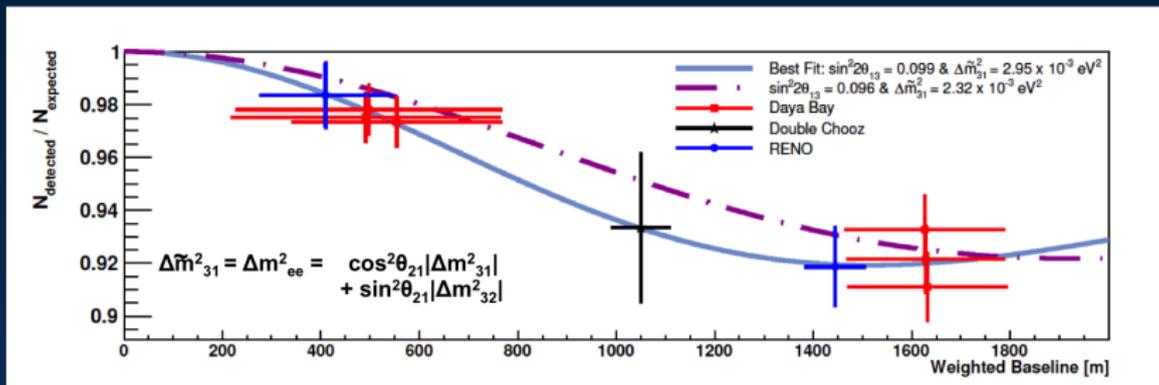
Reactor $\bar{\nu}_e$ spectrum measurements



- ▶ First to report unexpected features, later confirmed by Daya Bay, RENO
- ▶ DC site layout simplifies measurement
- ▶ May aid future reactor ν experiments

JHEP 10 (2014) 086 / arXiv:1406.7763 [hep-ex],
arXiv:1210.3748 [hep-ex]

Δm_{ee}^2 measurements



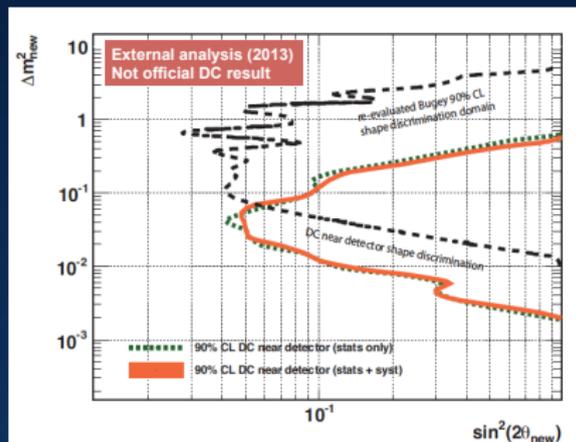
- ▶ Unique DC Far Detector baseline strongly enhances global rate-only fit
- ▶ Two-detector data will also allow DC-only, rate+shape fit
- ▶ Comparison with accelerator $\Delta m_{\mu\mu}^2$ tests 3ν model

Phys. Lett. B 725 (2013) 271-276 / arXiv:1304.6259 [hep-ex]
 (Independent paper by subset of DC collaborators)

Sterile ν sensitivity

- ▶ Expect some sensitivity to oscillations in range $\Delta m_{41}^2 \sim 10^{-3} - 1 \text{ eV}^2$
- ▶ Sensitivity enhanced by single-reactor-on time
- ▶ DC study in progress

Unofficial example of shape-only sensitivity:



arXiv:1303.0310 [hep-ex]
(Independent paper by
subset of DC collaborators)

Summary

$\theta_{13} \rightarrow \delta_{CP}$, mass hierarchy, θ_{23} octant

- ▶ DC measurements

- ▶ Most recent (n-Gd in Far Detector): $\sin^2 2\theta_{13} = 0.090^{+0.032}_{-0.029}$
- ▶ Two-detector precision may reach ~ 0.01

- ▶ Unique DC assets

- ▶ Reactor-off data
- ▶ Reactor Rate Modulation analysis
- ▶ Reactor error suppression from site geometry
- ▶ Novel analysis techniques

Summary

...and beyond θ_{13} \rightarrow mass hierarchy, sterile ν , ...

- ▶ Techniques and inputs for future experiments
 - ▶ New e^+ (vs. e^-) identifier
 - ▶ Neutrino directionality
 - ▶ Reactor $\bar{\nu}_e$ spectrum
- ▶ Additional physics measurements
 - ▶ Δm_{ee}^2
 - ▶ Sterile ν



Coming in 2015:
New n-H θ_{13} analysis
First two-detector θ_{13} analysis

...

